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To Mr. R.T. Popple
Manager
Radioactivity Management
and Environmental Protection

BRUCE "A" CHARCOAL FILTER STUDY

C.H. Cheh

Velocity measurements and tracer gas tests were carried out at Bruce "A" Unit 0 contaminated exhaust filter units, FR7 where the charcoal was recently replaced, and FR10 where the charcoal has not been changed for over two years. The objective of this study was to determine the effect of charcoal settling and compaction during the service life of the filter on flow distribution. The velocities at the outlet of the charcoal filter section were determined by using air velocity probes inserted into the filter units. Results showed that the air flow in FR7 was relatively even whereas in FR10, the air flow near the top was significantly higher than the bottom of the filter. A tracer gas study using Freon-12 was also carried out at Bruce "A". Results seemed to indicate that there was very little or no flow bypass in FR7 but significant (probably >50%) flow bypass in FR10.

INTRODUCTION

The contaminated exhaust systems in Ontario Hydro's nuclear generating stations consist of pre-filters, high efficiency particulate (HEPA) filters, charcoal (HECA) filters, and exhaust fans. These systems are designed to remove particulates and iodine from the exhaust air. The charcoal filters are arranged vertically and charcoal is added to the top of the filter to fill the filters. The main objective of this study was to determine the effect of charcoal settling and compaction during the service life of a filter on flow distributions in the filters.

In this study, the flow distributions at the outlet of exhaust filters FR7 and FR10 at Bruce "A" Unit 0 were determined. The charcoal in FR7 was changed just before the study, whereas the charcoal in FR10 had not been changed for over two years. Velocities at the outlet of the test canisters in these filter units were also determined. A tracer gas study was carried out in an attempt to quantify the amount of flow bypass in the filters.

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EQUIPMENT AND EXPERIMENTAL PROCEDURE

The equipment used and procedures followed in the velocity measurements and tracer gas study are discussed in the following.

Velocity Measurements

A probe support that could be inserted 3 m into the filter through a 3.2-cm hole and could traverse along three horizontal axes was designed and assembled as shown in Figure 1. Two velocity meters were used for velocity measurements, namely the TSI 1650 air velocity meter and the Anemotherm air meter. The velocity probe of each of the meters could be fitted to the probe support and inserted into the filter at the station. However, due to the presence of a 5-cm section of pipe welded to the 3.2-cm holes on the filter units at the station, the 23-cm section that was vertical to the main probe support could not be inserted into the filter. The velocity probes could only be inserted straight into the filter or at a slight angle to measure the velocities at some locations near the outlet of the charcoal filter. The probe was placed as close to the centre line between the two vertical charcoal filter plates as possible (see Figure 2).

The velocities at the charcoal filter and test canister outlets of filters FR7 and FR10 at Bruce "A" were determined. The TSI 1650 air velocity meter was used initially. Because of a broken connection in this meter, the Anemotherm air meter was used in the latter part of the experiment. The TSI 1650 velocity probe was calibrated by the manufacturer following the tests at the station and found to be very accurate (+0.1 m/s at 3.0 m/s). The Anemotherm air meter was then calibrated using the TSI 1650 velocity probe. The calibration data for both probes are summarized in the appendix.

Tracer Gas Study

Laboratory Experiments:

A brief tracer gas study was carried out in an attempt to quantify the bypass flow in the charcoal filters. Three tracer gases, namely NH_3, SF_6 and Freon-12, were tested in the laboratory. Freon-12 was selected for this study.

A portable infra-red analyzer (MIRAN 1A manufactured by Foxoboro) was used for gas analysis. The wave length and path length of the analyzer were set at 9.18 μm and 21 m, respectively. The analyzer has a sample volume of approximately 5.6 L. A 1000-μL/L Freon-in-air gas mixture was prepared and a gas dilution system was assembled with mass flow controllers to dilute the gas mixture with air from a compressed air cylinder to the desired concentration at a flow rate of 5.5 L/min. The diluted gas stream was used to calibrate the analyzer over the concentration range of 0.2 to 1 μL/L. The calibration curve is shown in the appendix. Calibration data obtained on different dates showed very little difference.

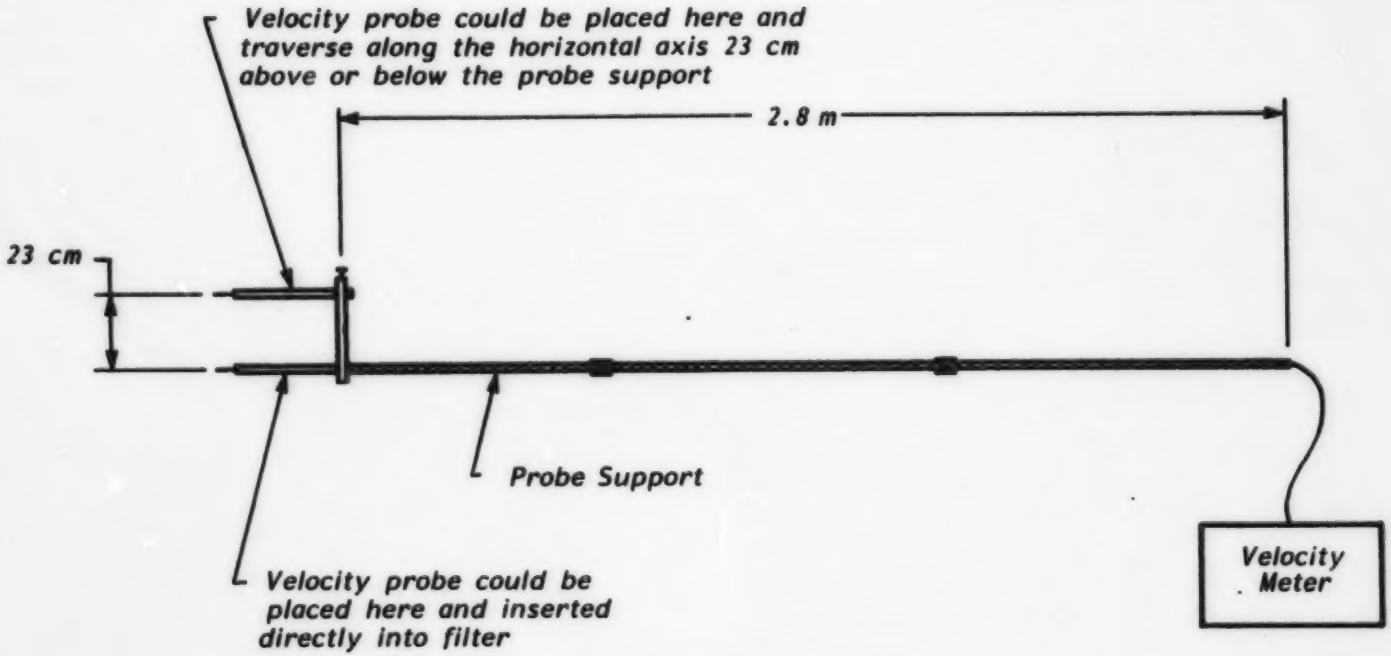
Velocity probe could be placed here and traverse along the horizontal axis 23 cm above or below the probe support
2.8 m
23 cm
Probe Support
Velocity probe could be placed here and inserted directly into filter
Velocity Meter

FIGURE 1

SCHEMATIC DIAGRAM OF VELOCITY PROBE AND PROBE SUPPORT

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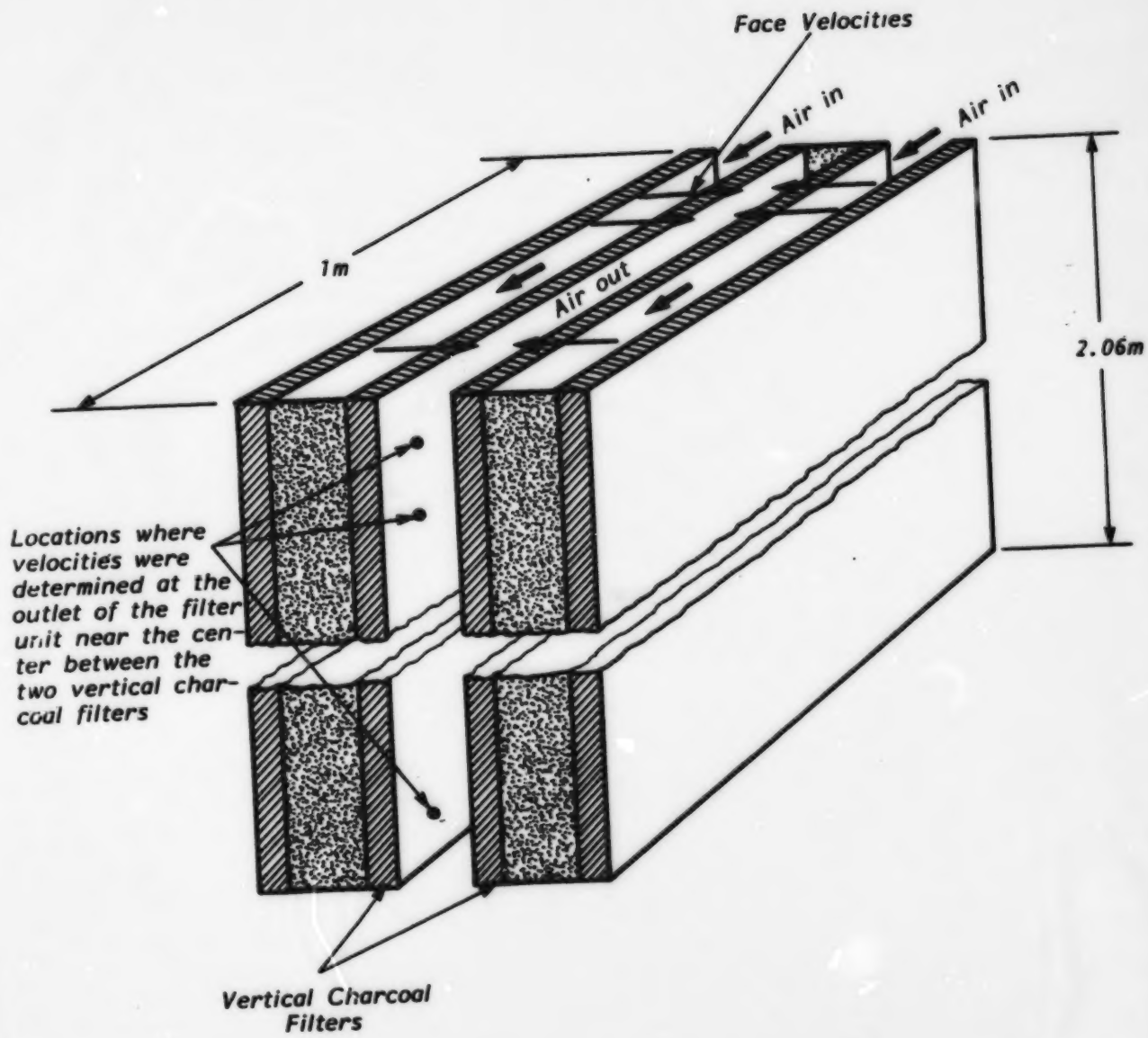
Face Velocities
Air in
Air in
1m
Air out
2.06m
Locations where velocities were determined at the outlet of the filter unit near the center between the two vertical charcoal filters
Vertical Charcoal Filters

FIGURE 2

FLOW SCHEME IN CHARCOAL FILTERS

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The breakthrough curves of a 5-cm diameter, 2.5-cm thick charcoal filter cartridge with and without flow bypass were determined in the laboratory. A schematic diagram of the equipment set-up is shown in Figure 3. Air supplied by compressed air cylinders was mixed with a 1000-μL/L Freon-12 in air gas to dilute the Freon concentration to 1 μL/L at a total flow rate of 25 L/min. Flow rates of both gases were controlled by mass flow controllers. The gas mixture could pass through or bypass the charcoal filter cartridge. The flow rates in the bypass line and the charcoal filter line were controlled by two valves, one in each of the two lines. The flow rate in the bypass line was measured by a rotameter. At the outlet of the charcoal filter, a flow of 5.5 L/min was diverted to the MIRAN 1A analyzer for analyzing its Freon concentration continuously. The output signal of the analyzer was recorded by a recorder (Philips Model PM 8251).

Field Experiments:

Tracer gas tests were carried out at Bruce "A" Unit 0 filters FR7 and FR10. A schematic diagram of the tracer gas injection, sampling, and analysis system is shown in Figure 4. Pure Freon-12 was released from a standard high pressure gas cylinder through a 0.95-cm copper tube. The copper tube was inserted into the centre of the inlet duct of the filter unit through a 1.9-cm pipe in the inlet duct. The Freon flow rate was controlled at 450 mL/min by a mass flow controller calibrated for pure Freon gas.

The gas sampling system consisted of a 0.95-cm copper sampling tube, a particulate filter, a rotameter, and a vacuum pump. The sampling tube was inserted into the centre of the outlet duct of the filter unit through a 1.9-cm pipe in the duct. The gas sample was drawn through the sampling tube and the particulate filter, before entering the MIRAN 1A analyzer. Downstream of the analyzer was the rotameter, and the vacuum pump was connected to the outlet of the rotameter to provide the suction. A sample flow rate of 5.5 L/min was maintained throughout the experiments. The MIRAN 1A analyzer was used in the station to determine the Freon concentration in the gas samples. The signal from the analyzer was recorded by a recorder (Philips Model PM 8251) continuously.

Two tracer gas experiments were carried out, one at each of the two filter units, FR7 and FR10. For each experiment, Freon was injected into the filter unit for about 30 minutes. The Freon concentration at the outlet of the filter unit was determined during the Freon injection and was continued for another 30 minutes after the Freon injection was stopped. During the experiment in Filter FR10, gas samples at various locations upstream and downstream of the HEPA filter were also analyzed.

RESULTS AND DISCUSSION

Velocity Measurements

The velocity distributions at the outlet of the charcoal filters in FR7 and FR10 were determined and are summarized in Table 1 and 2, respectively. For FR7, the velocities near the top of the filter were in the range of 5.9 to 8.4 m/s. The velocities near the bottom of the filter unit were in a similar range of 5.9 to 7.4 m/s. The velocities near the bottom seemed to be only slightly lower than the velocities near the top. However, for FR10, the velocities near the top of

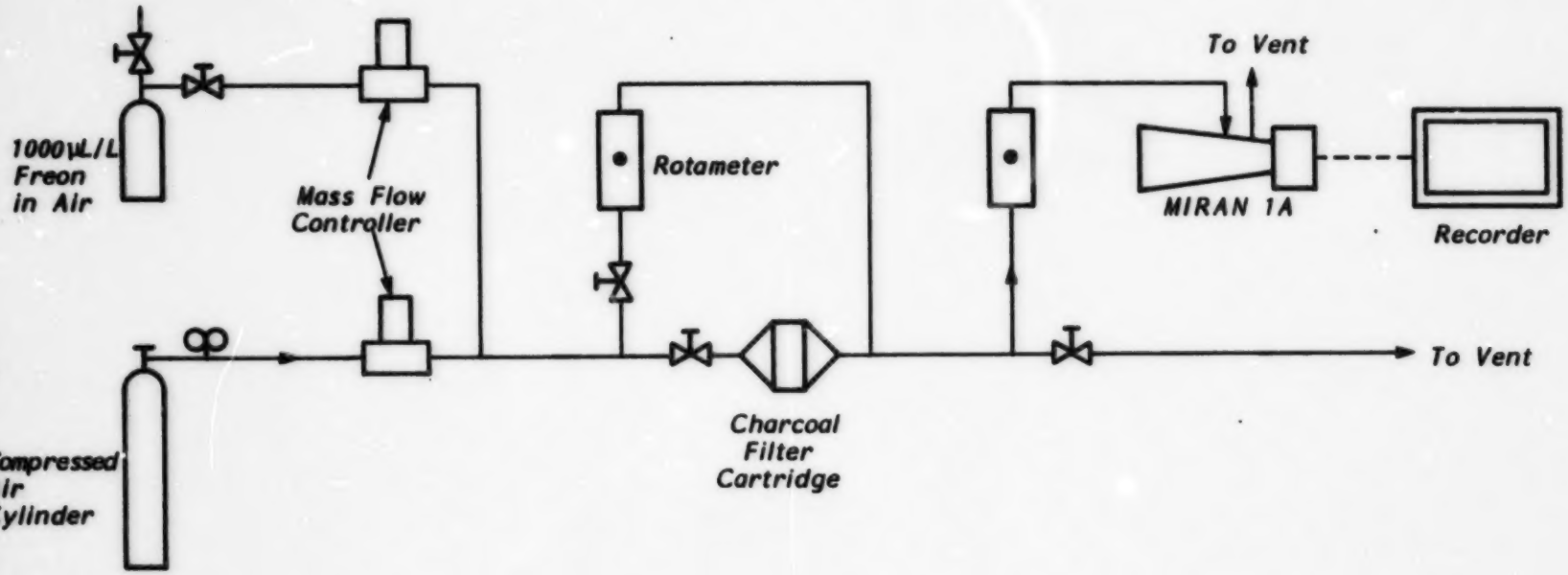

FIGURE 3

SCHEMATIC DIAGRAM OF THE LABORATORY FILTER FLOW BYPASS TEST EQUIPMENT

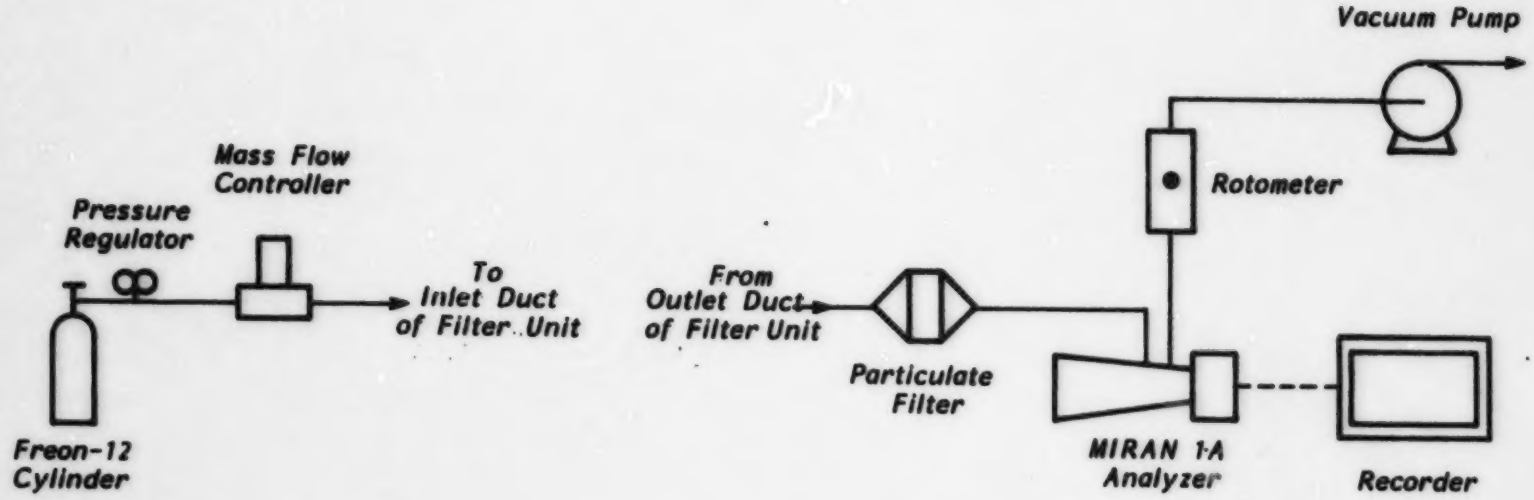

FIGURE 4

SCHEMATIC DIAGRAM OF EQUIPMENT USED FOR TRACER GAS STUDY AT BRUCE 'A'

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the filter (in the range of 5.9 to 7.9 m/s) were significantly higher than the velocities near the bottom of the filter (in the range of 3.7 - 6.1 m/s). The velocities near the bottom of the filter in one of the outlet slots were as low as 51% of the velocities near the top of the filter.

It is most likely that the relative difference between the face velocities near the top and the bottom of the filter was even greater. As the air was flowing in the 1-m section between the vertical filters before exiting the charcoal filter section to where the velocities were measured (as illustrated in Figure 2), the flow would be redistributed and the velocity profile at the exit of the charcoal filter section would be more even than the vertical profile of the face velocities. The significantly higher air flow near the top of this filter (FR10) was probably due to flow bypass in this area. The charcoal in the filter had probably been settling and become more compact in the lower section and less compact in the upper section of the filter. Loss of charcoal in the upper section of some of the filters might have occurred, and led to the significantly higher air flow in this area.

The velocities at the outlet of the test canisters near the middle of the filter unit in FR7 and FR10 were determined and found to be 0.95 - 1.0 m/s and 1.9 - 2.0 m/s for the canisters in FR7 and FR10, respectively. These velocities seemed to be much higher than the designed face velocity of 0.2 m/s for charcoal filters.

Tracer Gas Study

The main objective of this study was to determine the amount of air that might be bypassing the charcoal filter. An ideal tracer gas for this study should have the following characteristics:

(i) non-toxic, chemically stable, and low background concentration;

(ii) readily detectable at low levels and preferably continuously using simple detection techniques such as the infrared spectrometer (continuous) or gas chromatography (non-continuous); and

(iii) strongly absorbed by charcoal and would not break through or desorb easily.

Three tracer gases, namely NH_3, SF_6, and Freon-12, were tested. The sensitivity of the MIRAN analyzer for NH_3 was poor. Very high NH_3 concentration in the gas flow was required for analysis. The detection limit of the MIRAN for SF_6 was very low in the range of 0.02 to 0.05 µL/L. However, SF_6 did not seem to be significantly adsorbed by charcoal at low SF_6 concentrations in the gas phase. Freon-12 was selected for this study because it could be detected at low levels (approximately 0.1 µL/L), and it was relatively more adsorbed by the charcoal. The breakthrough curve of the Freon-12 seemed to be reproducible for different degrees of flow bypass in the laboratory filter testing.

A series of experiments was carried out in the laboratory with the equipment set up as shown in Figure 3. The air flow rate through the 5-cm diameter filter was 25 L/min with a face velocity of 0.2 m/s. The breakthrough curves of these experiments are shown in Figure 5. With no flow bypass, the outlet Freon concentration increased rapidly during the first two minutes of the experiment

TABLE 1

Summary of Velocity Measurements at Bruce "A", Unit 0, FR7

Vertical Position of Probe Measured from the Top of the Filter Unit (cm)	Number of the air outlet slot counting from the man-hole side of the filter unit											
	1	2	3	4	5	6	7	8	9	10	11	12
	Velocities in m/s											
5				6.5	7.2	8.4	6.8	6.5				
25	3.8	6.1	5.9	6.2	7.0	8.0	6.1	6.2	5.6			
91	3.2	5.6	6.7	6.5	5.6	5.0	6.5	6.5				
147			6.0	6.7	7.0(7.8)	6.8(6.8)	7.1(7.2)	7.1(7.2)	7.0			
165	3.6	6.5-6.6 (5.4)	6.4-6.5 (5.6)	6.7(5.9)	6.5-6.6 (6.4)	6.6(6.8)	7.1(6.8)	6.5(6.5)	6.8	5.8-5.9	3.4	
188			7.4(6.5)	7.3(6.8)	7.1(6.8)	6.4(7.2)	5.9(7.0) (6.8)	6.8-6.9	7.1			

( ) Velocities measured by Anemotherm Air meter, all others measured by TSI 1650 air velocity meter.

TABLE 2

Summary of Velocity Measurements at Bruce "A", Unit 0, FR10

Vertical Position of Probe Measured from the Top of the Filter Unit (cm)	Number of the air outlet slot counting from the man-hole side of the filter unit							
	1	2	3	4	5	6	7	8
	Velocities in m/s							
5			7.2	5.9	5.9	7.3	7.0	7.9
25	3.8	5.4	5.9	5.3	6.5	7.0	7.0	7.9
91	3.8	6.2	7.0	6.0	6.4	6.2	6.2	5.8
147				5.0	5.3	5.3	6.4	6.4
165	3.8		3.8	3.9	3.9	3.1	4.4	4.8
188			4.1	3.9	3.9	3.7	5.0	6.1

and reached about 0.21 µL/L. After the initial 5 minutes, the outlet concentration increased slowly at a constant rate and reached 0.45 µL/L in about 30 minutes. For the experiments with 30% and 50% flow bypass, the outlet concentrations reached 0.40 µL/L and 0.65 µL/L, respectively in about 2 minutes, and then the increase of outlet concentration became gradual after 4 minutes.

Results of the two tracer gas experiments carried out at Bruce "A" Unit 0 Filter FR7 and FR10 are also plotted in Figure 5. For FR7, the outlet Freon concentration started to increase gradually after one minute of Freon injection in the inlet duct and reached 0.50 µL/L after 30 minutes of Freon injection. The lack of rapid increase of outlet concentration indicated that there was probably very little flow bypass in this filter and that the Freon injected was breaking through the filter gradually.

For FR10, the outlet Freon concentration increased rapidly in the first 10 minutes after the start of Freon injection, reached 1.15 µL/L, and then increased gradually to about 1.2 µL/L in the next 5 minutes. The rapid increase of outlet concentration in the first 10 minutes indicated that there was most likely a significant fraction of the air flow bypassing the charcoal filter. In the laboratory experiment with 50% flow bypass, the outlet concentration increased rapidly only in the first 3 minutes and was less than 0.8 µL/L at 5 minutes whereas for FR10 at Bruce "A", the outlet concentration was greater than 0.9 µL/L and was still increasing rapidly after 5 minutes of Freon injection. This seemed to indicate that the flow bypass in FR10 might be significantly more than 50%.

The Freon concentrations of gas samples taken from upstream and downstream of the HEPA filters in FR10 were determined after Freon injection had started for 20 minutes. The Freon concentration of the gas samples varied depending upon the location of the sample taken. Freon concentrations of samples near the wall of the filter unit were found to be about 0.6 and 0.7 µL/L upstream and downstream of the HEPA filter, respectively, significantly lower than the Freon concentration at the outlet duct. It was, therefore, concluded that Freon was not evenly distributed upstream or downstream of the HEPA filters.

CONCLUSIONS AND RECOMMENDATIONS

1. Results of the velocity measurements showed that the air flow in FR7 was relatively evenly distributed, whereas in FR10 the air flow was significantly higher in the upper section of the filter. This higher flow in FR10 was probably due to charcoal settling in the filter that led to flow bypass near the top of the filter.

2. Based on the results of the tracer gas experiments, it was concluded that very little or no flow bypass occurred in FR7 but significant (>50%) flow bypass was present in FR10.

3. Freon-12 is not an ideal tracer gas for studying flow bypass for charcoal filters because it is not completely retained by the charcoal. A tracer gas that is completely adsorbed by charcoal may be more suitable for flow bypass studies. To study the bypass of organic iodide in charcoal filters, the use of methyl iodide as the tracer gas will provide the information directly and would be the preferred method.

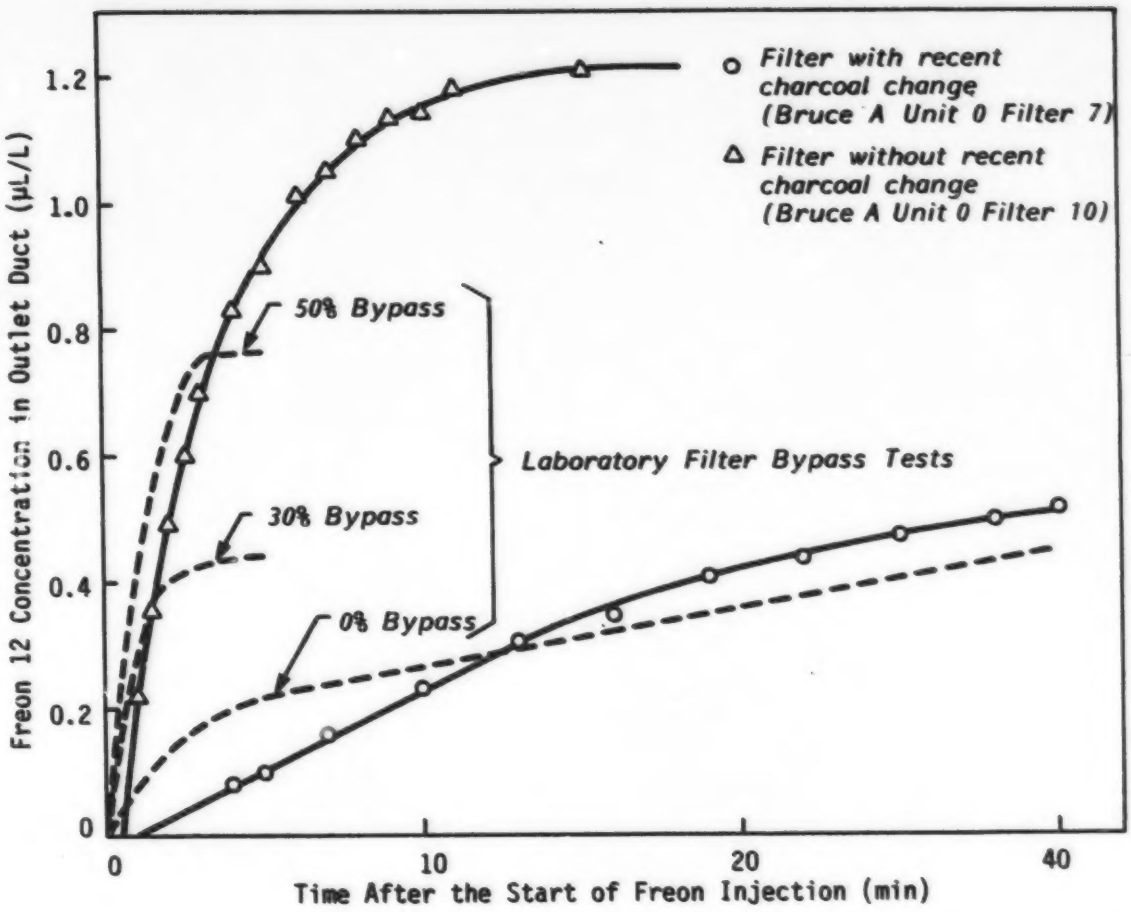

FIGURE 5

LABORATORY AND IN-STATION TRACER GAS STUDY RESULTS

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4. Since SF_6 is found to be not significantly adsorbed by charcoal, it can be used to determine gas flow rates in the filter units by injecting SF_6 at a known, fixed rate into the inlet duct and determining the SF_6 concentration at the outlet duct.

Approved:

O.A. Kupcis
Manager
Chemical Research Dept

Submitted:

C.K. Cheh
Senior Process Development Engineer
Environmental & Inorganic
Research Section

Reviewed by:

S.H. Hawthorne

S.H. Hawthorne
Unit Head, Process Development
Environmental & Inorganic
Research Section

kw

APPENDIX

EQUIPMENT CALIBRATION

The TSI 1650 air velocity meter was calibrated by the manufacturer and the results are summarized in Table A.1. The reading of the meter was found to be very close to the true velocity.

Table A.1

Calibration of the TSI 1650 Air Velocity Meter

True Velocity (m/s)	Metering Reading Before Adjustment (m/s)	Error (m/s)
0	0	0
3.0	3.10	+0.10
12.5	12.0	-0.5
30.0	30.0	0

The Anemotherm air meter was calibrated by determining the velocity at the same location downstream of a small blower. The corresponding readings of the two velocity meters are plotted in Figure A.1. This graph was used to convert the readings of the Anemotherm air meter to air velocities.

The calibration curve of the MIRAN 1A Infrared analyzer is shown in Figure A.2. The calibrations of the analyzer at different dates did not change significantly as shown in Figure A.2.

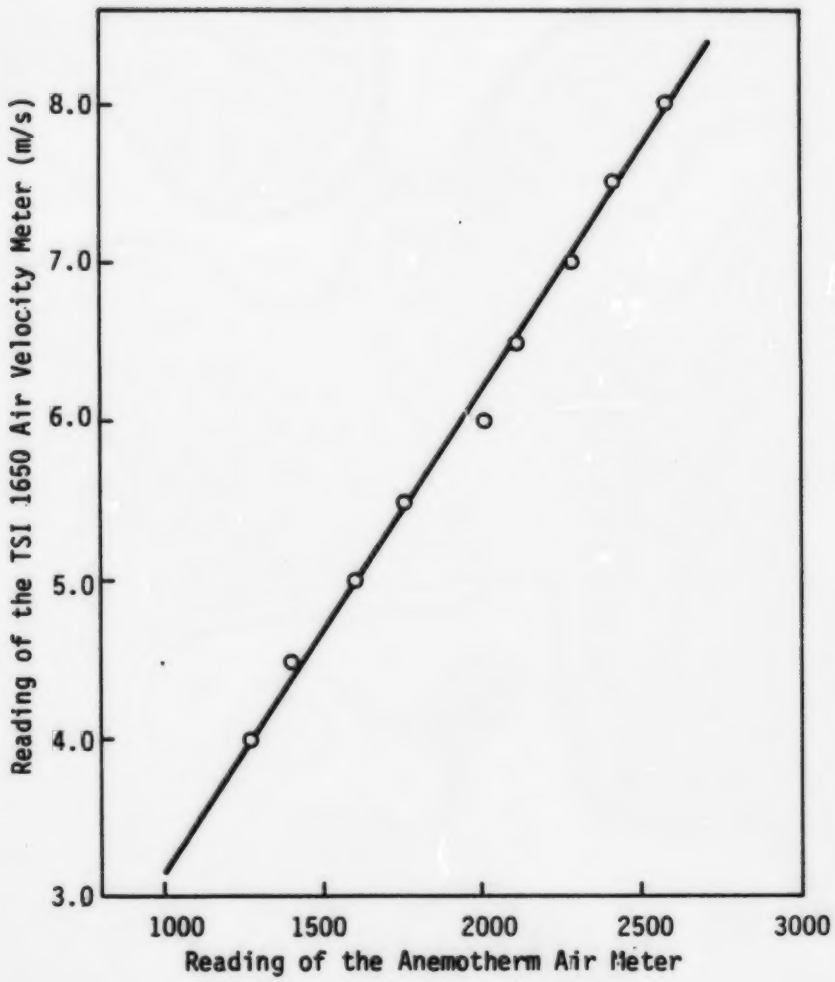

FIGURE A1
CALIBRATION OF THE ANEMOTHERM AIR METER

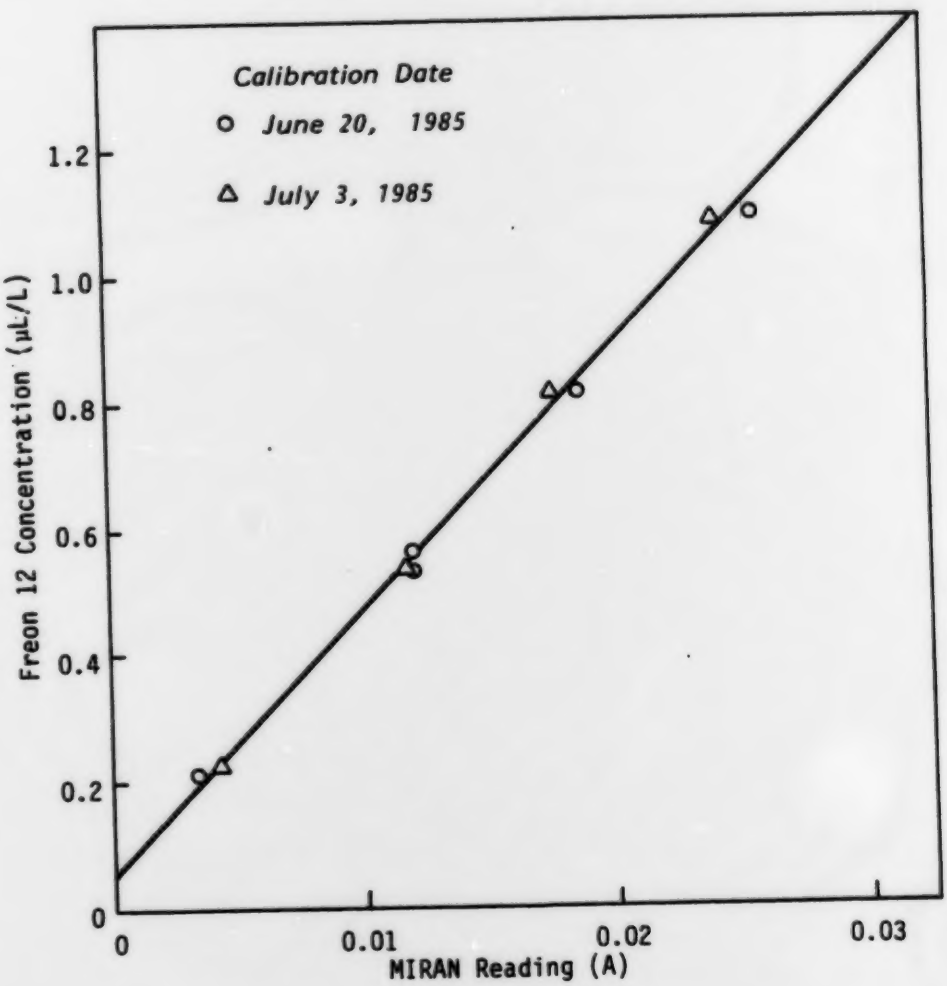

FIGURE A2

CALIBRATION OF THE MIRAN 1A ANALYZER WITH FREON-12